Dielectric Frequency Response and Temperature Dependence of Power Factor

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Megger Middle East

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Typical power factor values for oil insulated transformers and bushings

	Typical power factor values @ 20° C		
	"New"	"Old"	Warning/alert limit
Power transformers, oil insulated	0.2-0.4%	0.3-0.5%	> 0.5%
Bushings	0.2-0.3%	0.3-0.5%	> 0.5%

IEEE 62-1995 states; "The power factors recorded for routine overall tests on older apparatus provide information regarding the general condition of the ground and inter-winding insulation of transformers and reactors. While the power factors for most older transformers will also be <0.5% (20C), power factors between 0.5% and 1.0% (20C) may be acceptable; however, **power factors >1.0% (20C) should be investigated**."

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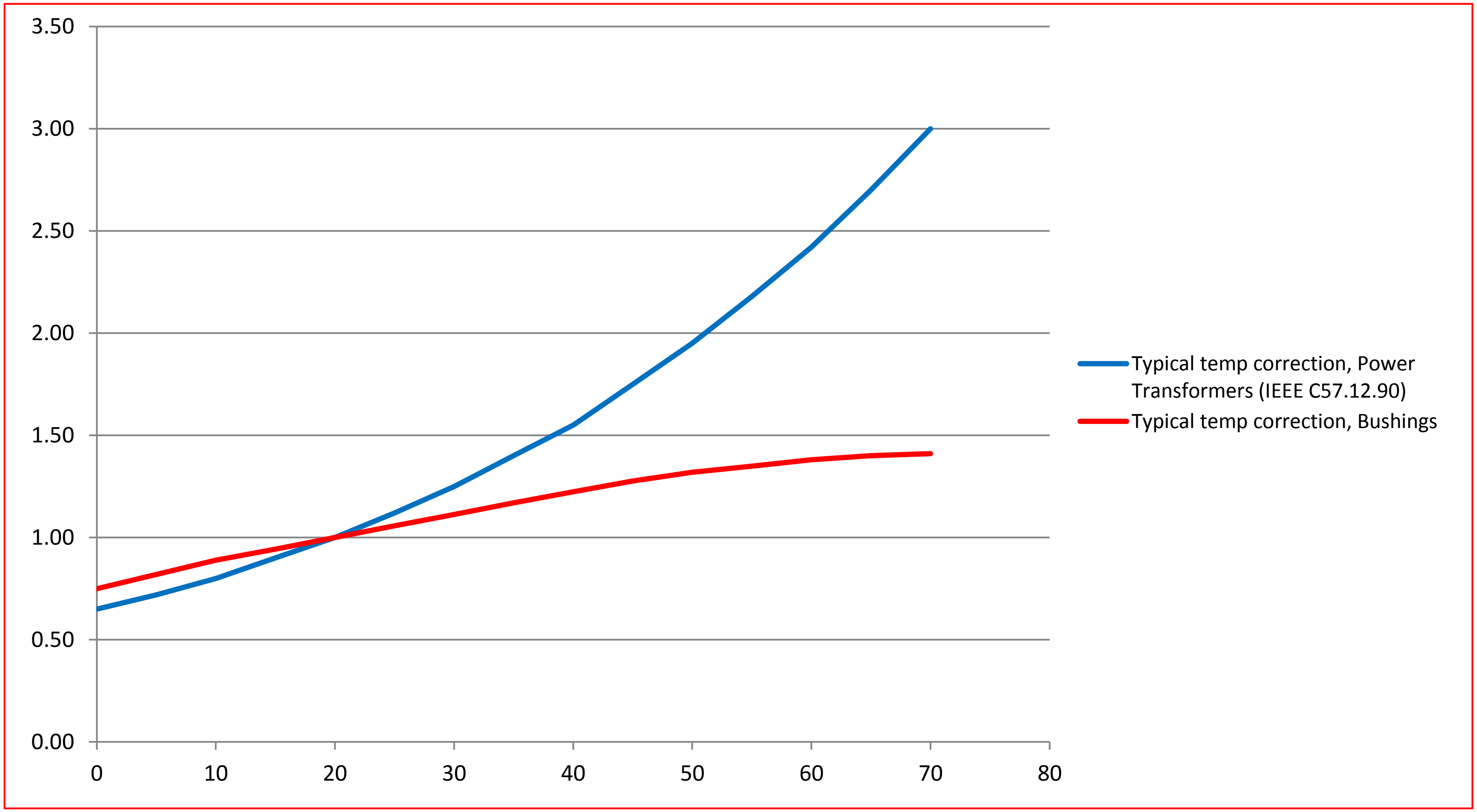
Typical power factor temperature correction



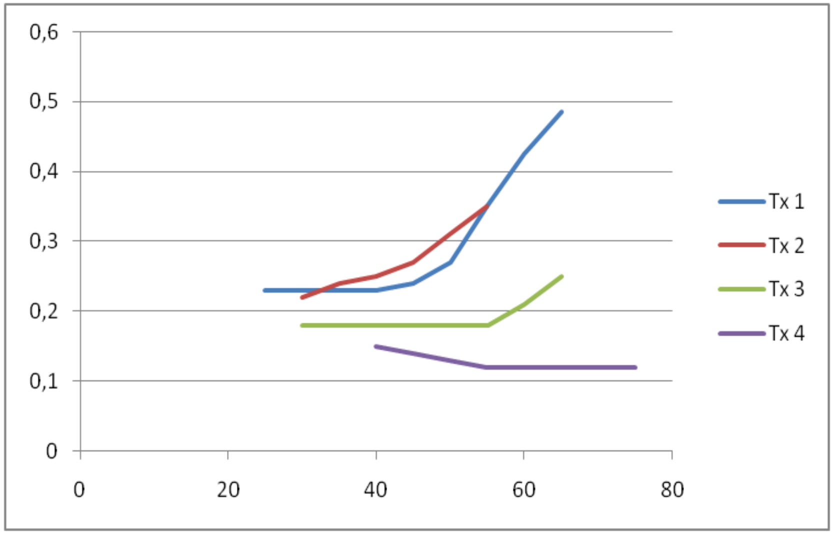
Temperature correction – in practice

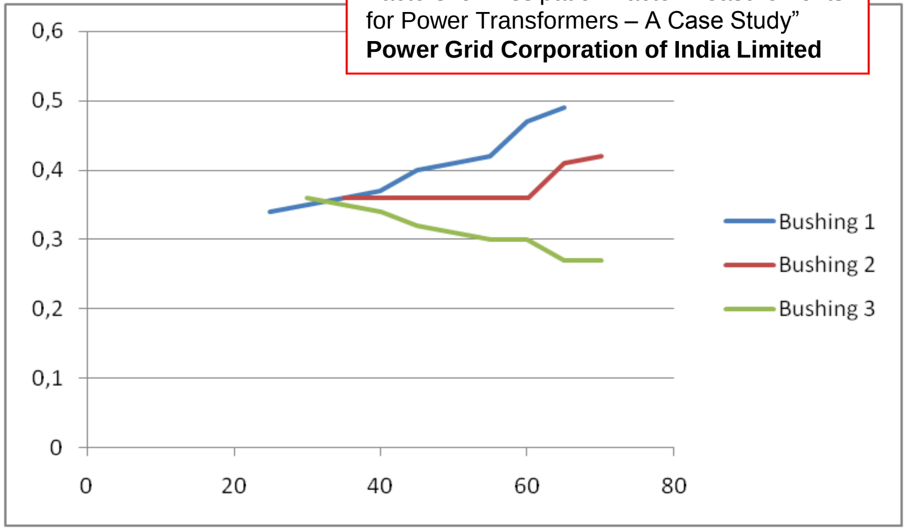
"Built-in temperature correction curves for different insulation materials are used to recalculate the measured results to reference conditions (20°C, 68°F). **The method of correction is depending on the type of insulation** and the relevant standard" (quoted from instrument manufacturer)

- Temperature correction is pending type of insulation
- Temperature correction is pending status of insulation
- Guessing game…

PF vs Temperature – Conclusions from a project

- Power factor values are affected by variation of temperature. In most cases (but not all), tan delta value increases with increase in temperature. Rate of change is different for different makes of the transformers and bushings
- The temperature correction factors (for correcting measured power factor to 20° C) are different for different makes. Hence temperature correction factors as given in IEEE/C57.12.90 can not be applied to these components





"Application of Temperature Correction Factors for Dissipation Factor Measurements for Power Transformers – A Case Study"
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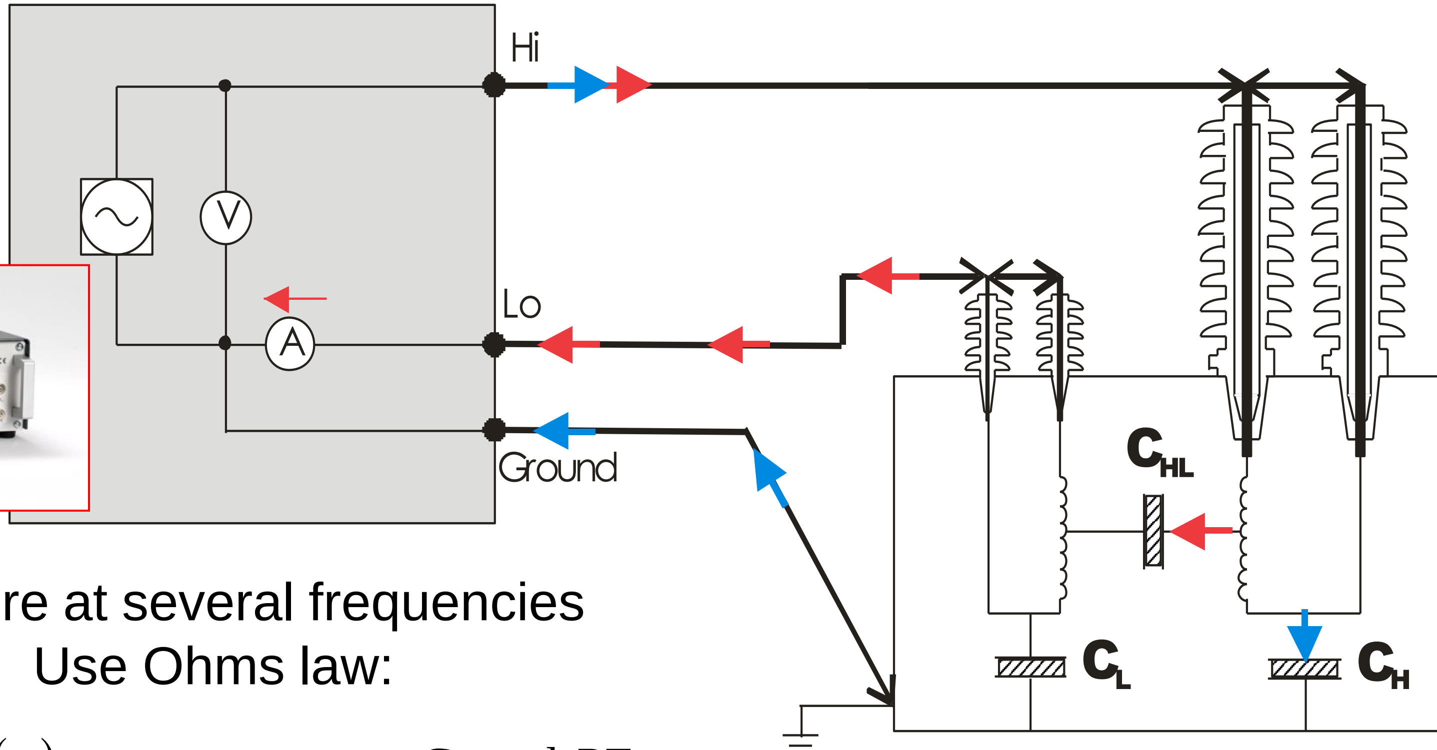
Dielectric Frequency Response Measurements
– Power factor from mHz to kHz



Measure at several frequencies
Use Ohms law:

$$Z(\omega) = \frac{U(\omega)}{I(\omega)} \qquad Z(\omega) \Rightarrow \begin{matrix} \mathrm{C, tand, PF} \\ (\varepsilon' \text{ and } \varepsilon'') \end{matrix}$$

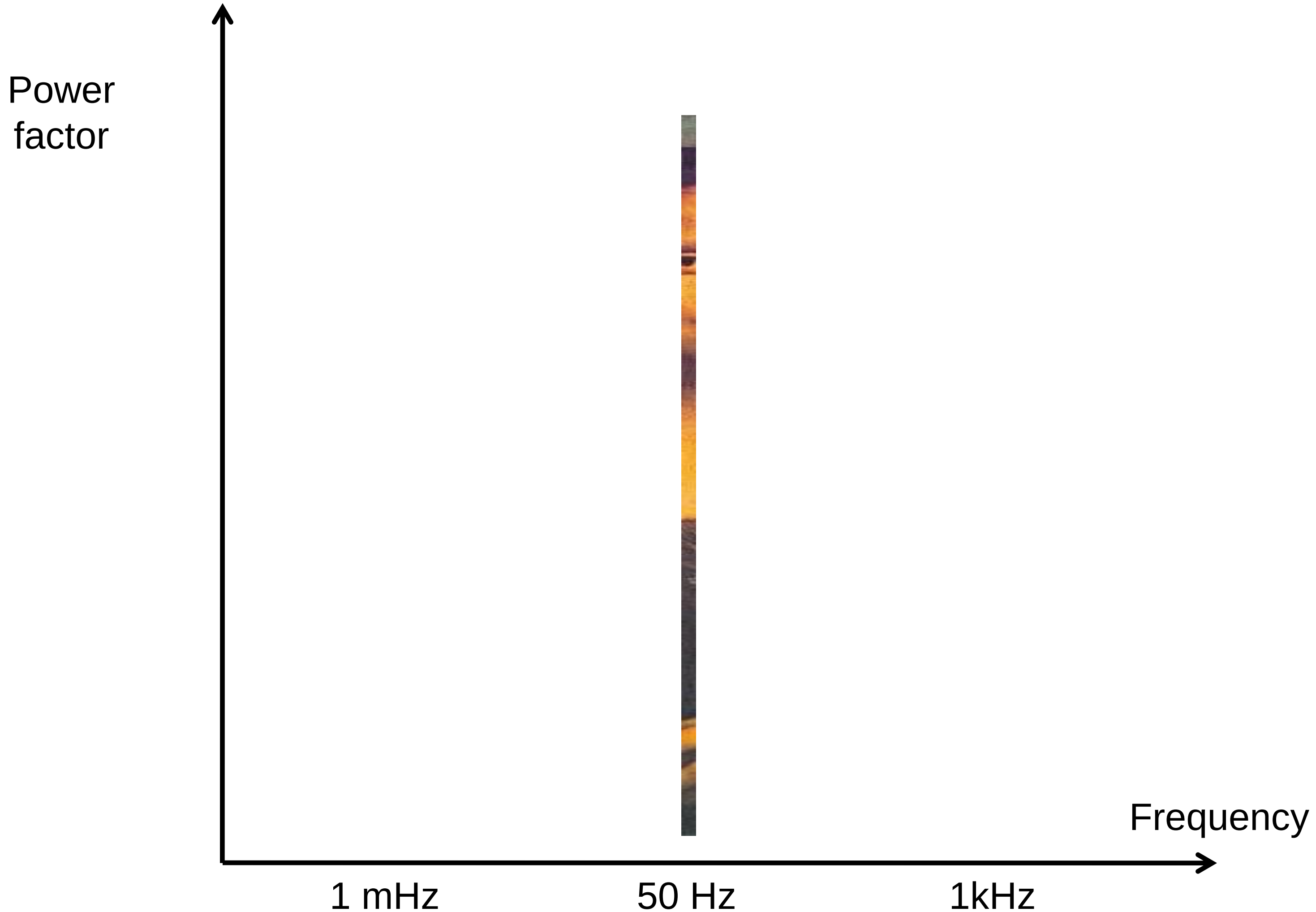
Dielectric Frequency Response

- Changes in insulating materials affect the power factor and capacitance
- Measurements over a frequency range, compared to traditional power factor testing, provides a lot more information on:
  - Insulation characteristics
  - Moisture in the cellulose insulation
  - Temperature dependence
  - Etc…

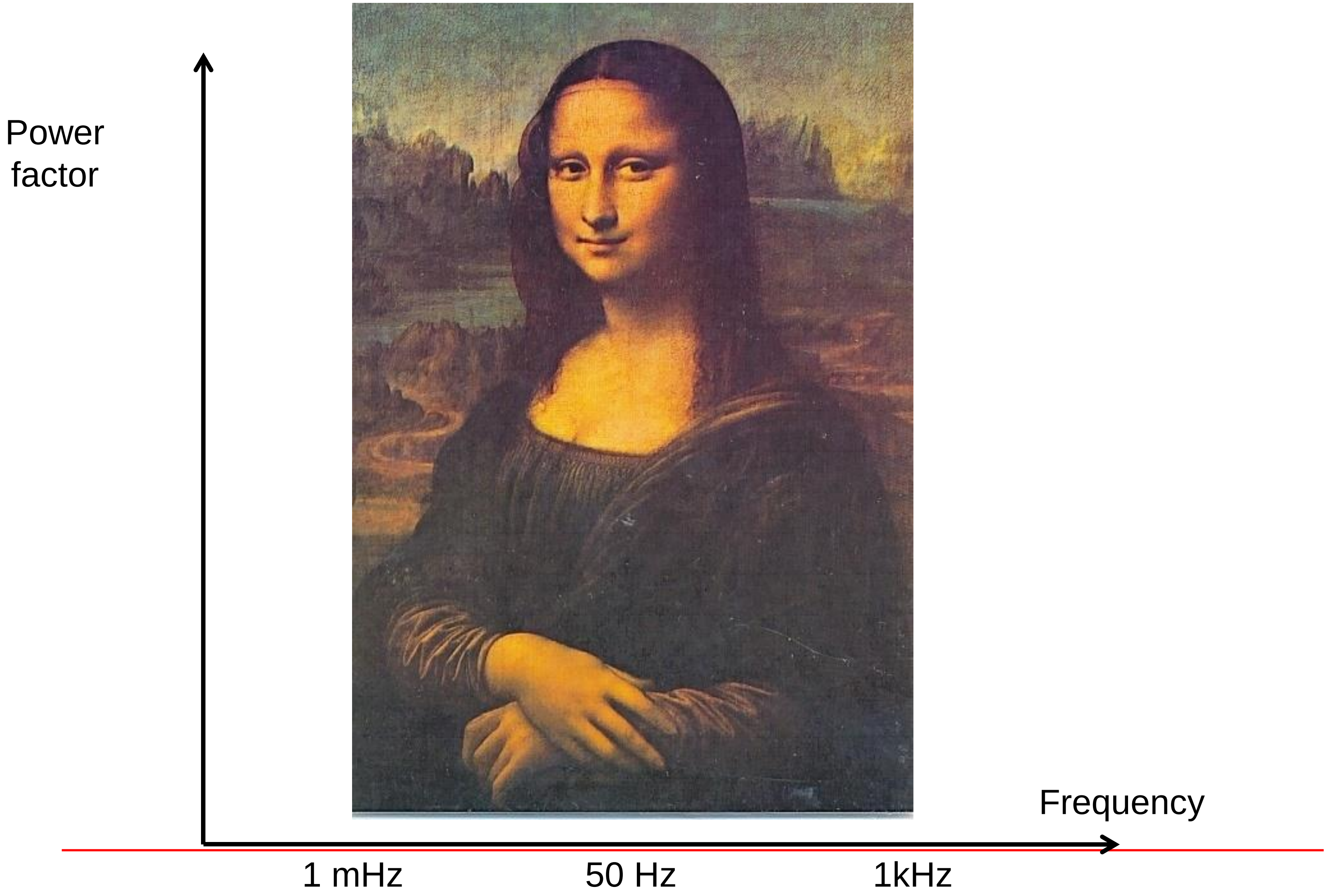
Insulation testing - 100 years of history

- **1870’s;** First systematic investigations of dielectric properties (Clausius and Mosotti)
- **1885;** The transformer is invented by Ottó Bláthy
- **1927;** First instrument for DC insulation testing is patented and released
- **1990;** ABB presents first results on dielectric response measurements on insulating materials (NORD-IS 1990)
- **1993;** Development of the first field instrument for Dielectric Frequency Response measurements is started by Dr. Peter Werelius
- **1995;** First field instrument for DFR delivered
- **1995-2005;** The interest in using DFR/FDS for investigating insulation properties is rapidly growing and numerous papers on the method and technology are presented at international conferences
- **2004;** CIGRE report 254, ”Dielectric Response Methods for Diagnostics of Power Transformers” is published
- **2006;** Project REDIATOOL reported at CIGRE, recommending DFR as a preferred method for moisture assessment of power transformers
- **2010;** CIGRE report 414 “Dielectric response diagnoses for transformer windings” is published

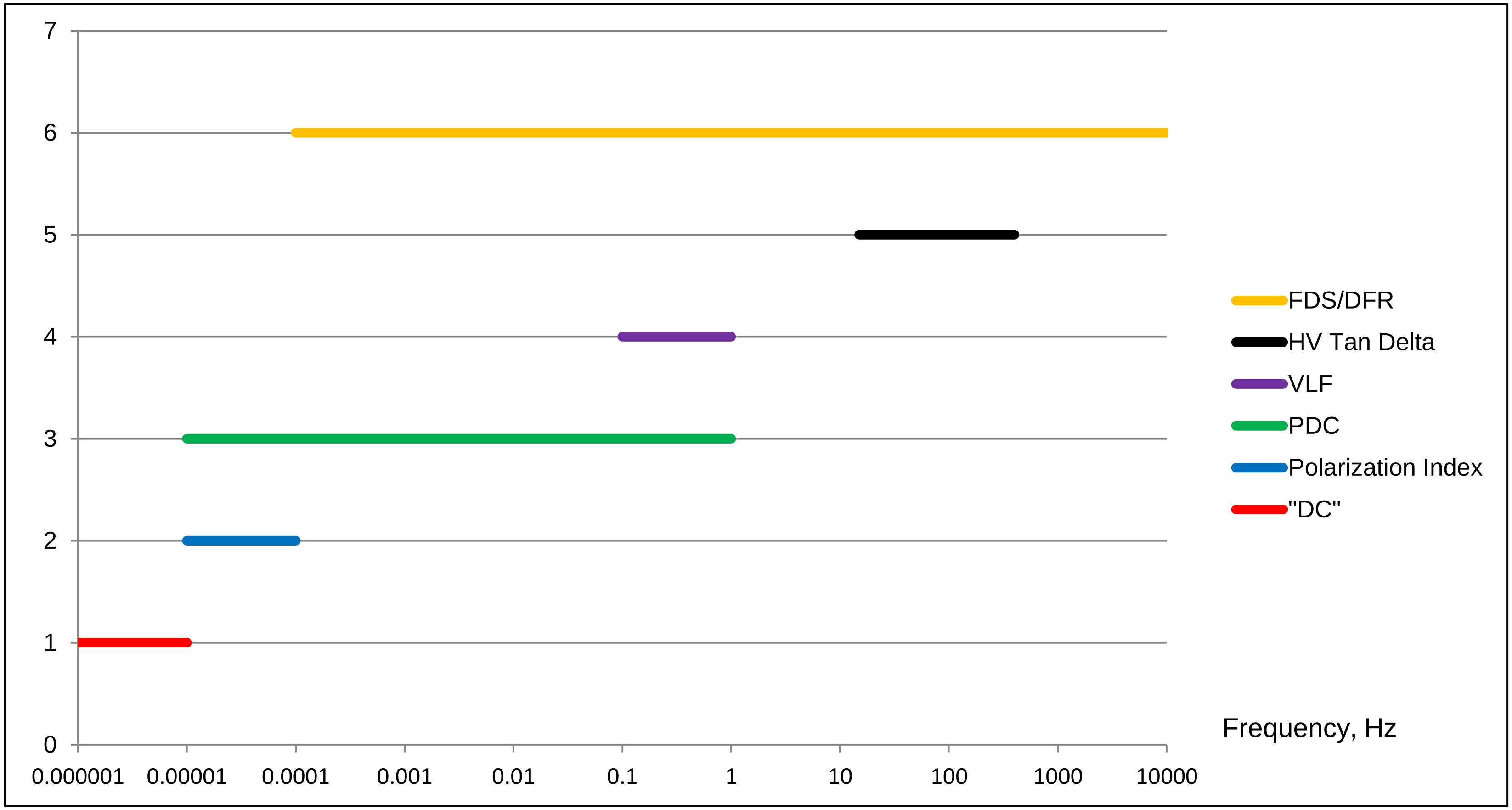
Traditional Power Factor Testing



Dielectric Frequency Response



Insulation testing/Dielectric response methods

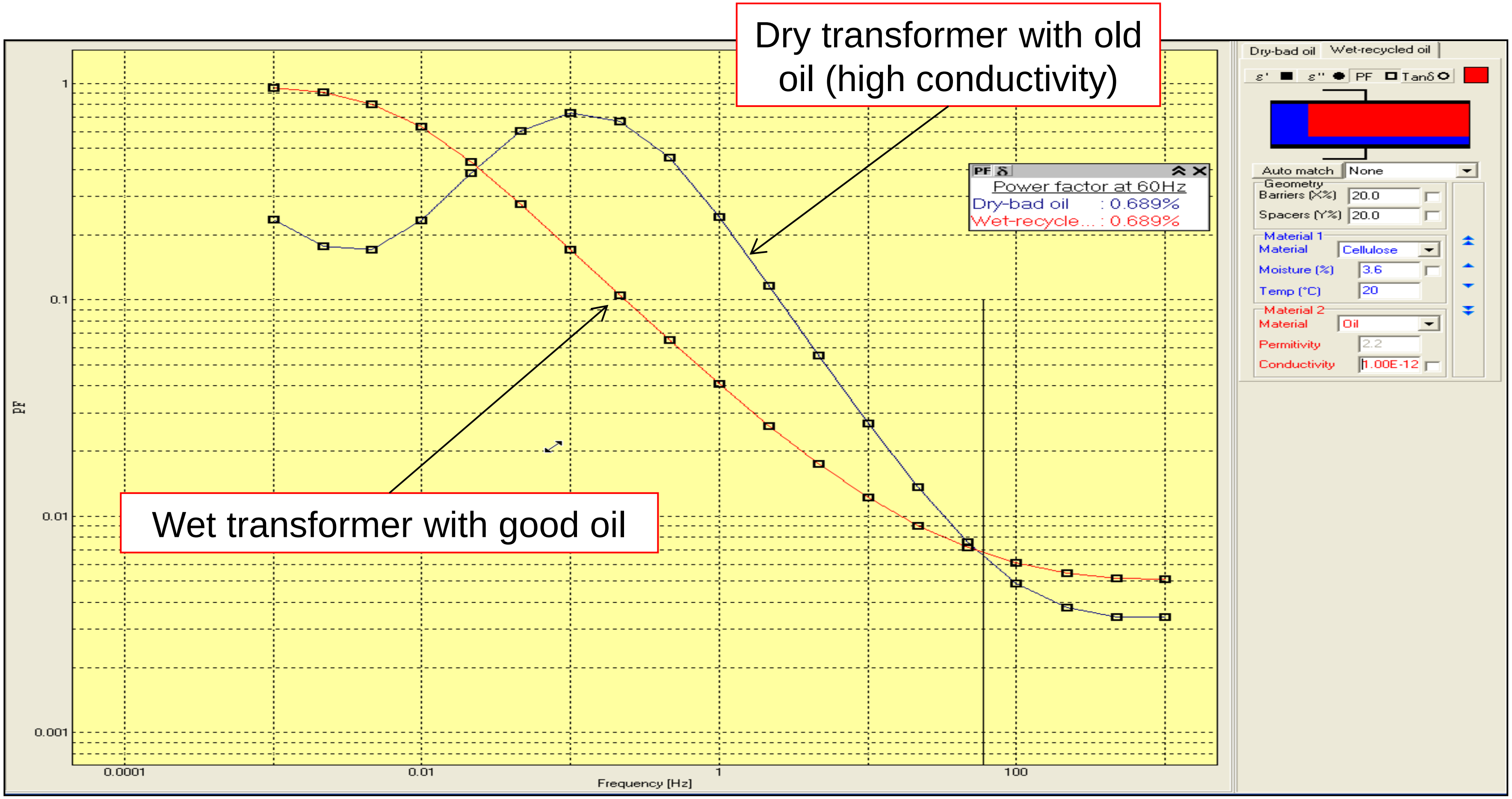


DFR Application Areas

- Power transformers
- Instrument transformers
- Bushings
- Motors and generators
- Cables
- Generic testing of insulation systems

Dielectric Frequency Response

- Investigating high single number PF data



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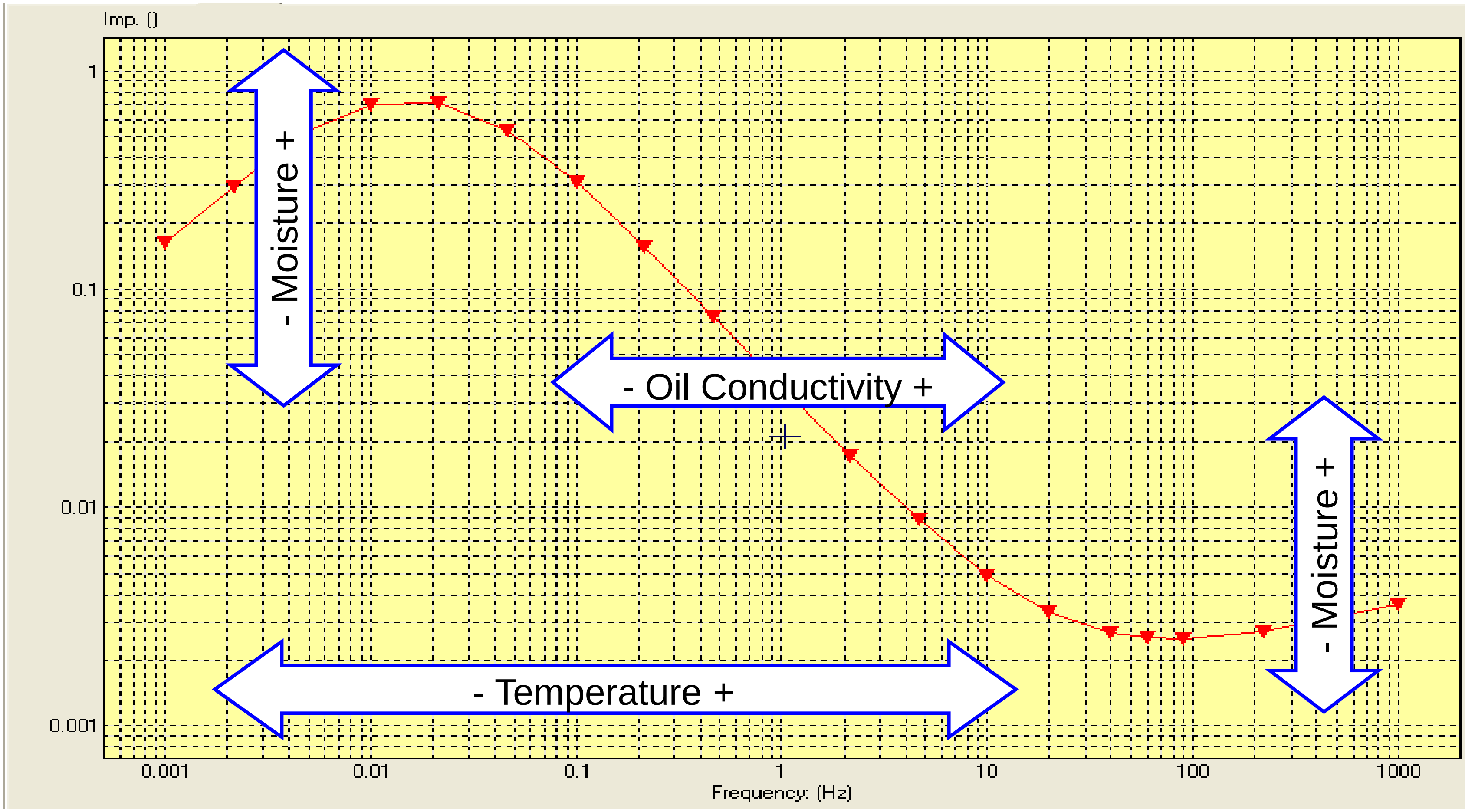
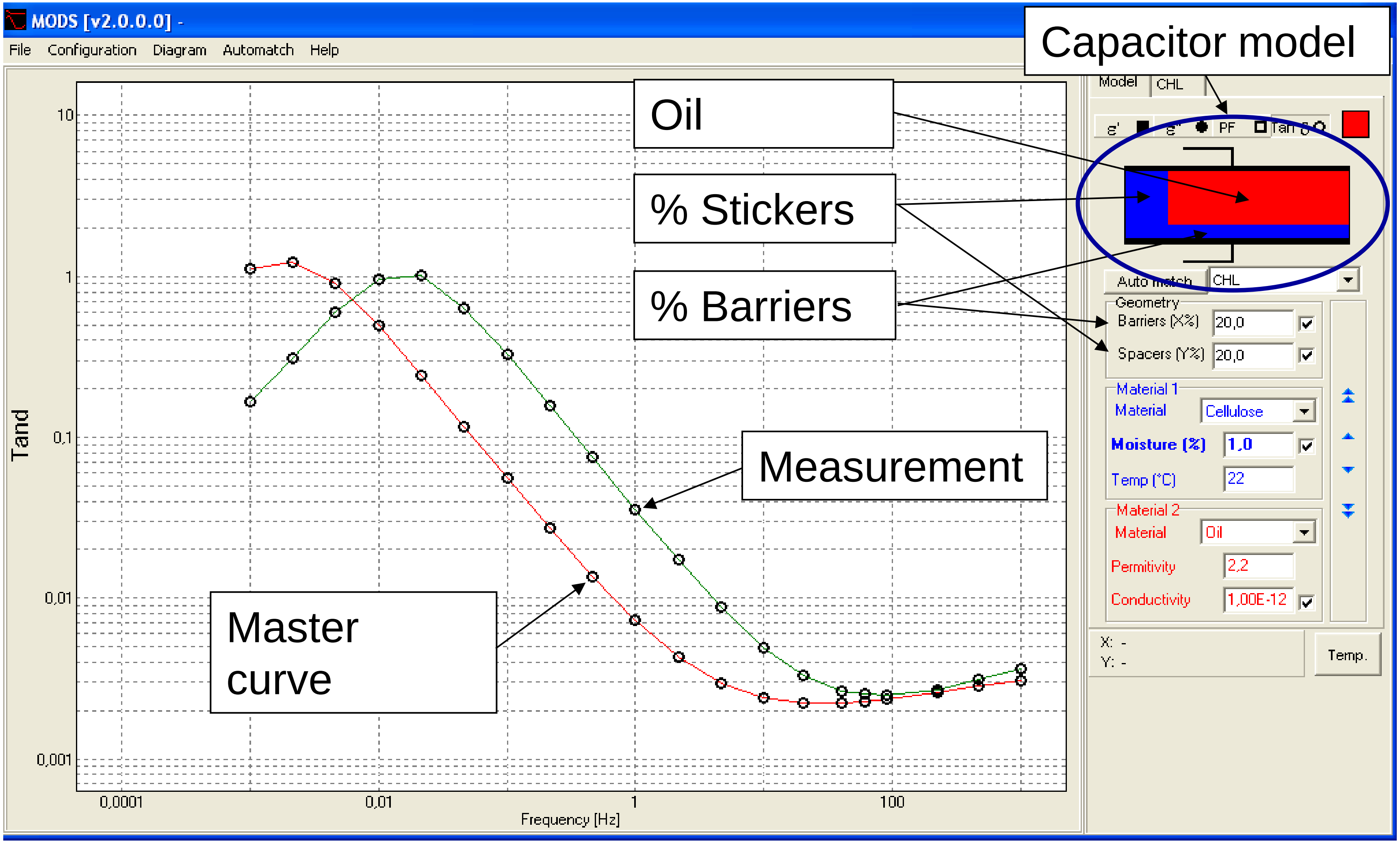
What affects the response?



DFR – Moisture estimation (1-2-3)



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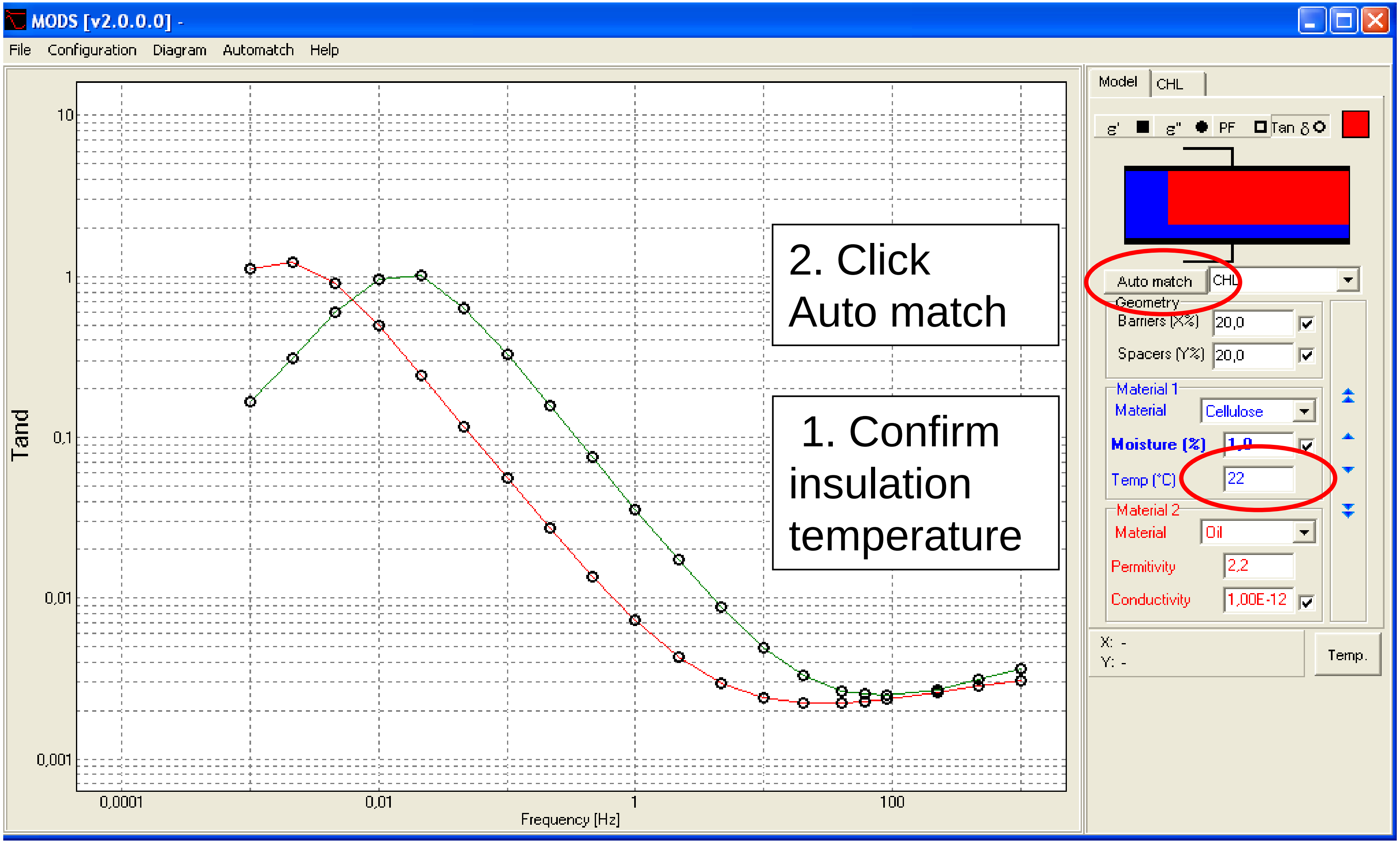

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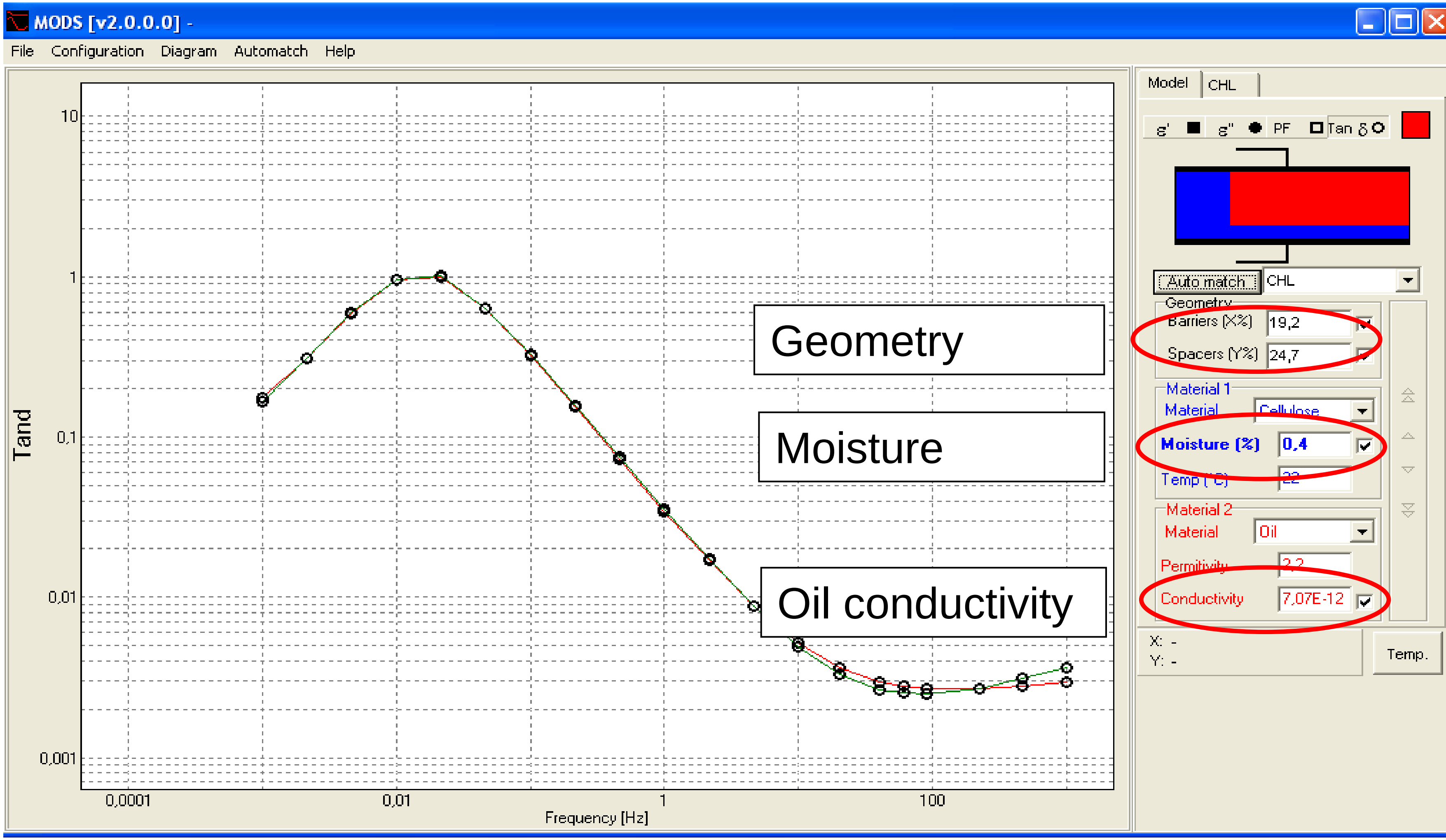
DFR – Moisture estimation – Results



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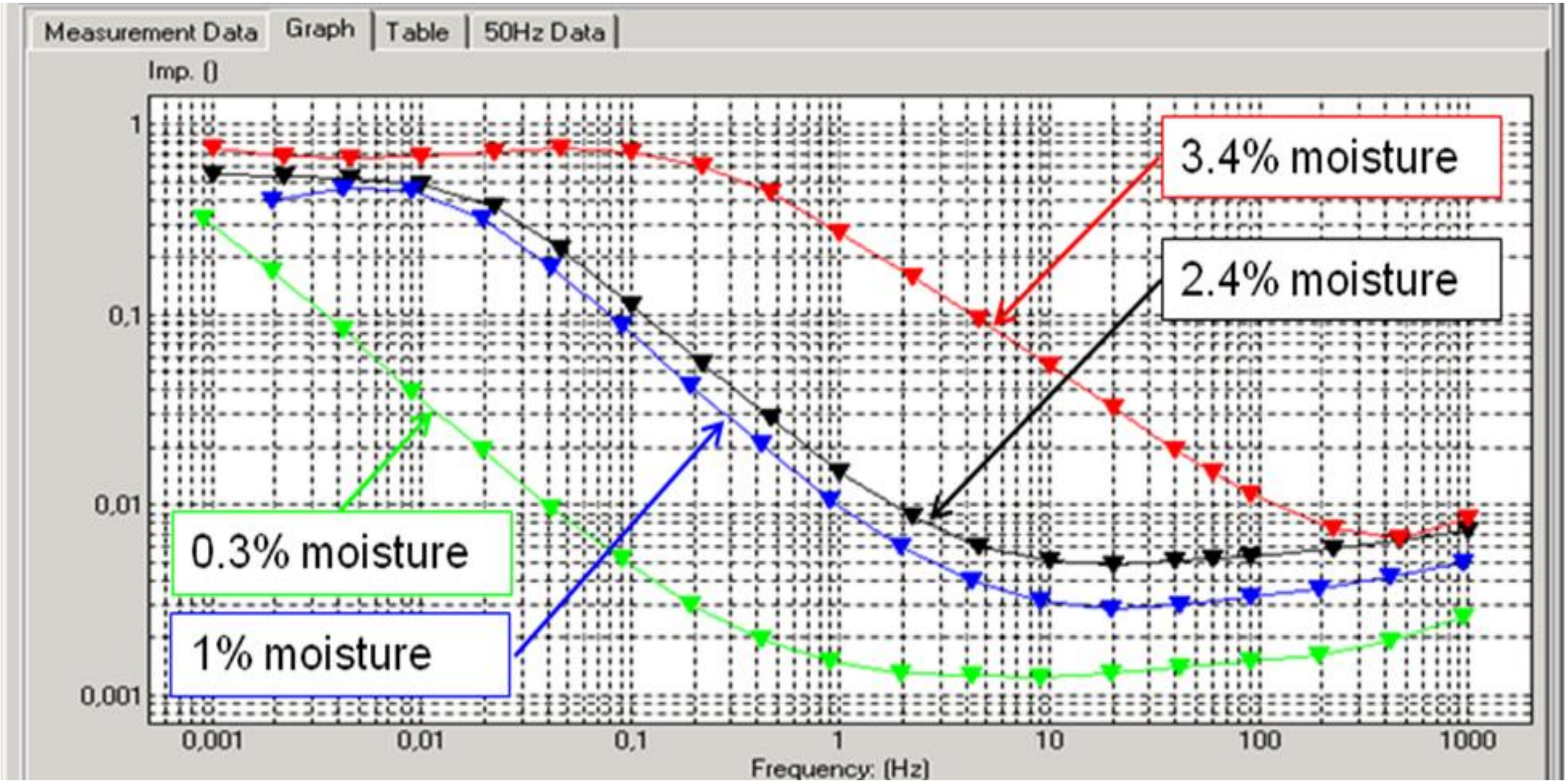
Typical DFR results for transfomers with various moisture content



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DFR and temperature dependence – ITC (intelligent temperature correction)

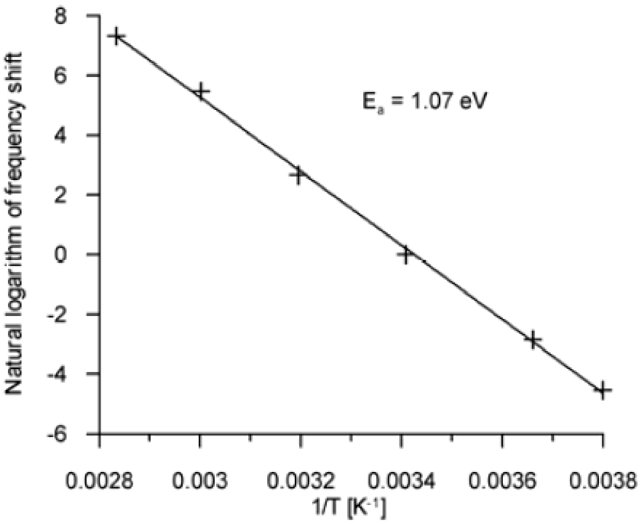
- Insulation properties changes with temperature
- Described by the Arrhenius equation and complex permittivity Debye function:
  - A measurement at e.g. 50 Hz, 20C corresponds to a measurement at higher frequency at higher temperature
- Various material have different activation energy
  - Dry paper typically around 1.0 eV
  - Oil-impregnated paper typically 0.9 – 1.0 eV
  - Mineral transformer oil typically 0.4 – 0.5 eV

DFR and temperature dependence

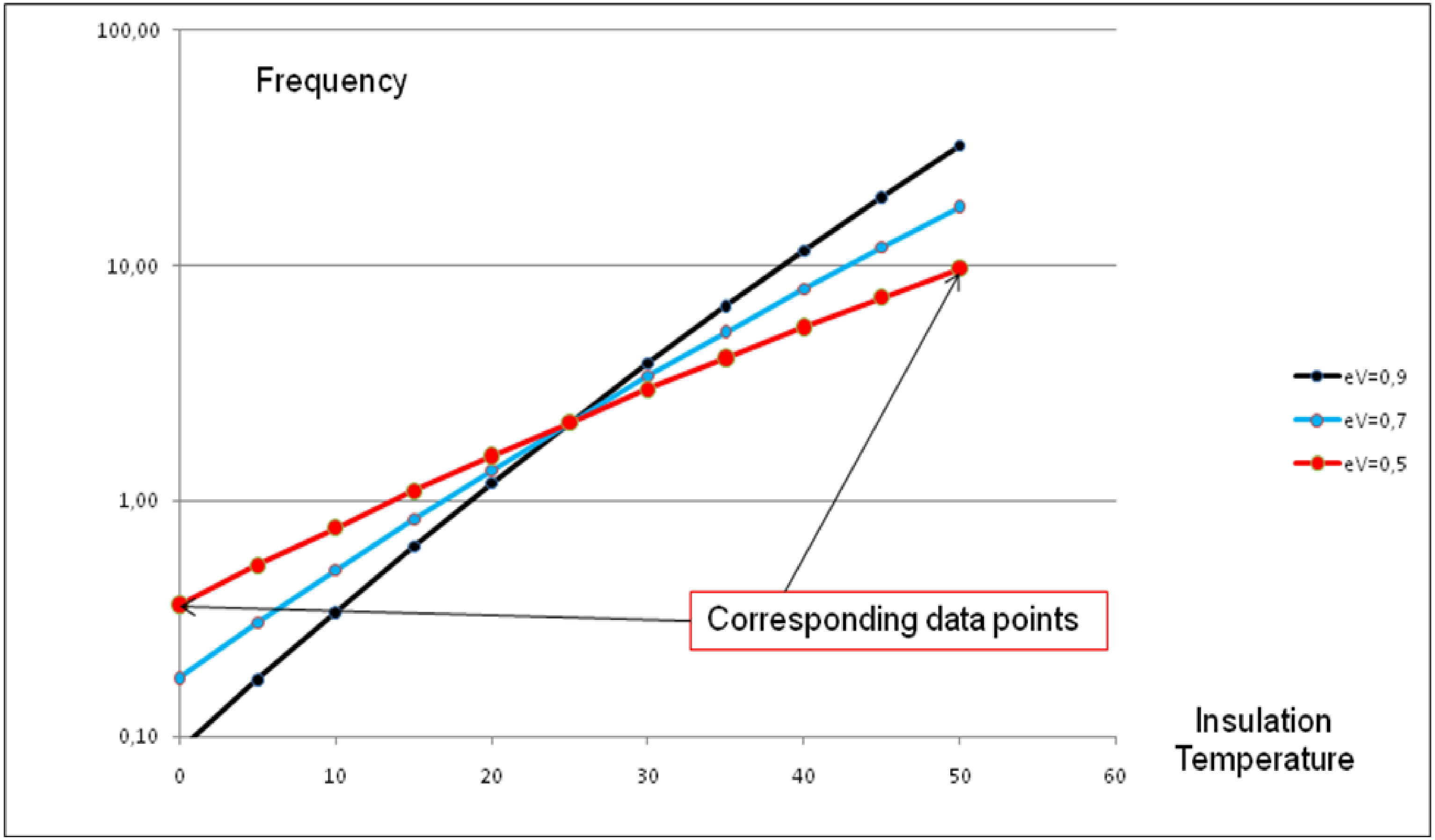
- K, Boltzmann constant
- Ea, Activation Energy
- Ƭ is relaxation time.
- Relative permittivity is a function of (-Ea/KT) in the logarithmic scale
- Conclusion: Change of temperature won't change the shape of the response in log-log scale, but only shifts the whole curve!

$$\hat{\varepsilon}(\omega) = \varepsilon_\infty + \frac{\Delta\varepsilon}{1 + i\omega\tau},$$

$$k = Ae^{-E_a/(k_B T)}$$



DFR data acqusition is pending insulation temperature

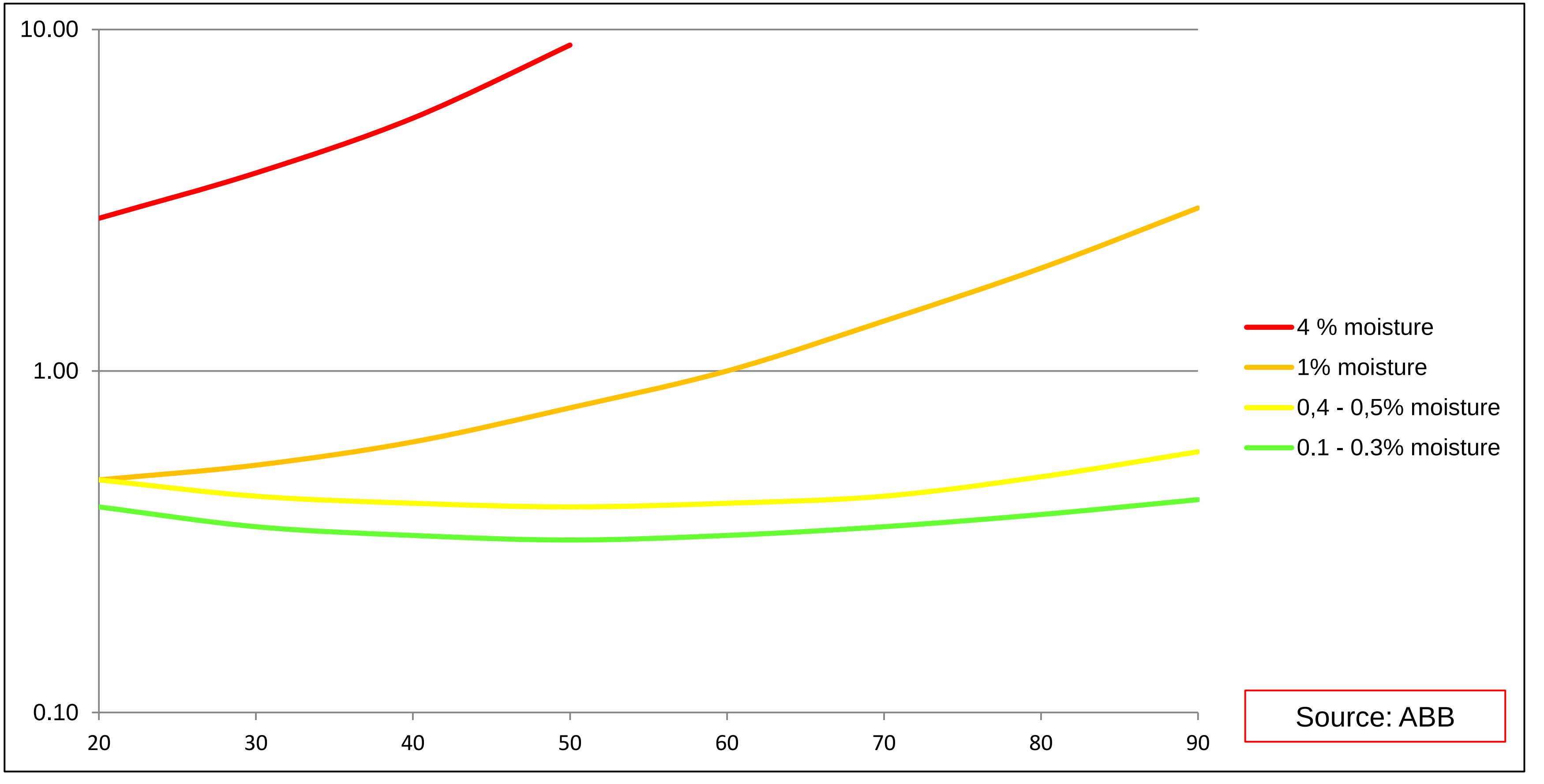


Bushings and power factor

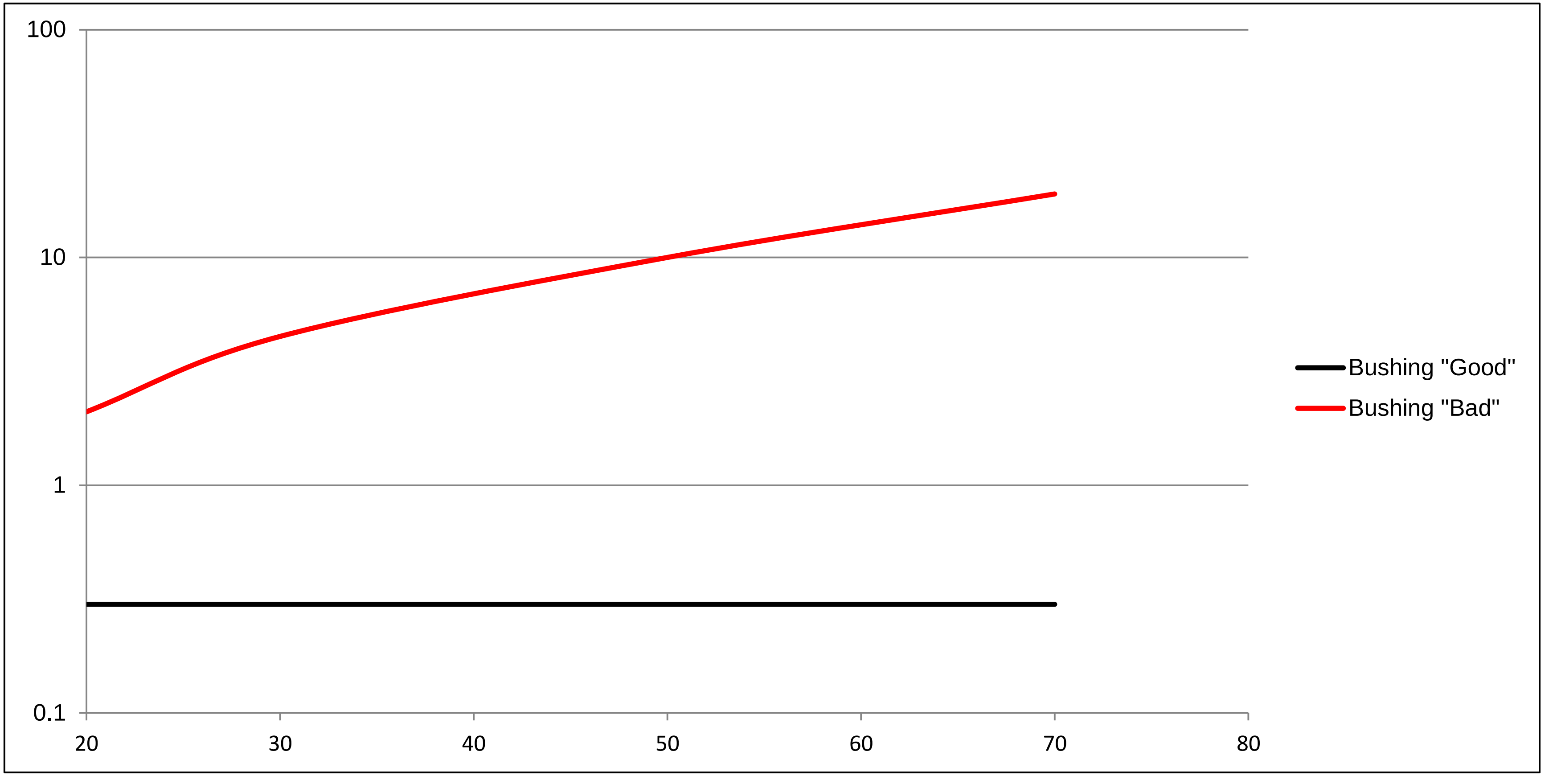
- The power factor is considered important for two main reasons:
  - Dielectric losses generate heat, which could result in premature ageing of the insulation if the bushing is not properly designed, or even worse, could lead to a thermal breakdown.
  - Quality check of the production process.
- The aim is to have a power factor that:
  - Shows just a small variation with temperature. Increasing dissipation factor with temperature indicates a moisture level in the main insulation above 1 %.
  - Remains stable during the bushing's entire service life. Increasing dissipation factor indicates moisture ingress and/or ageing of the insulation.

Source: ABB

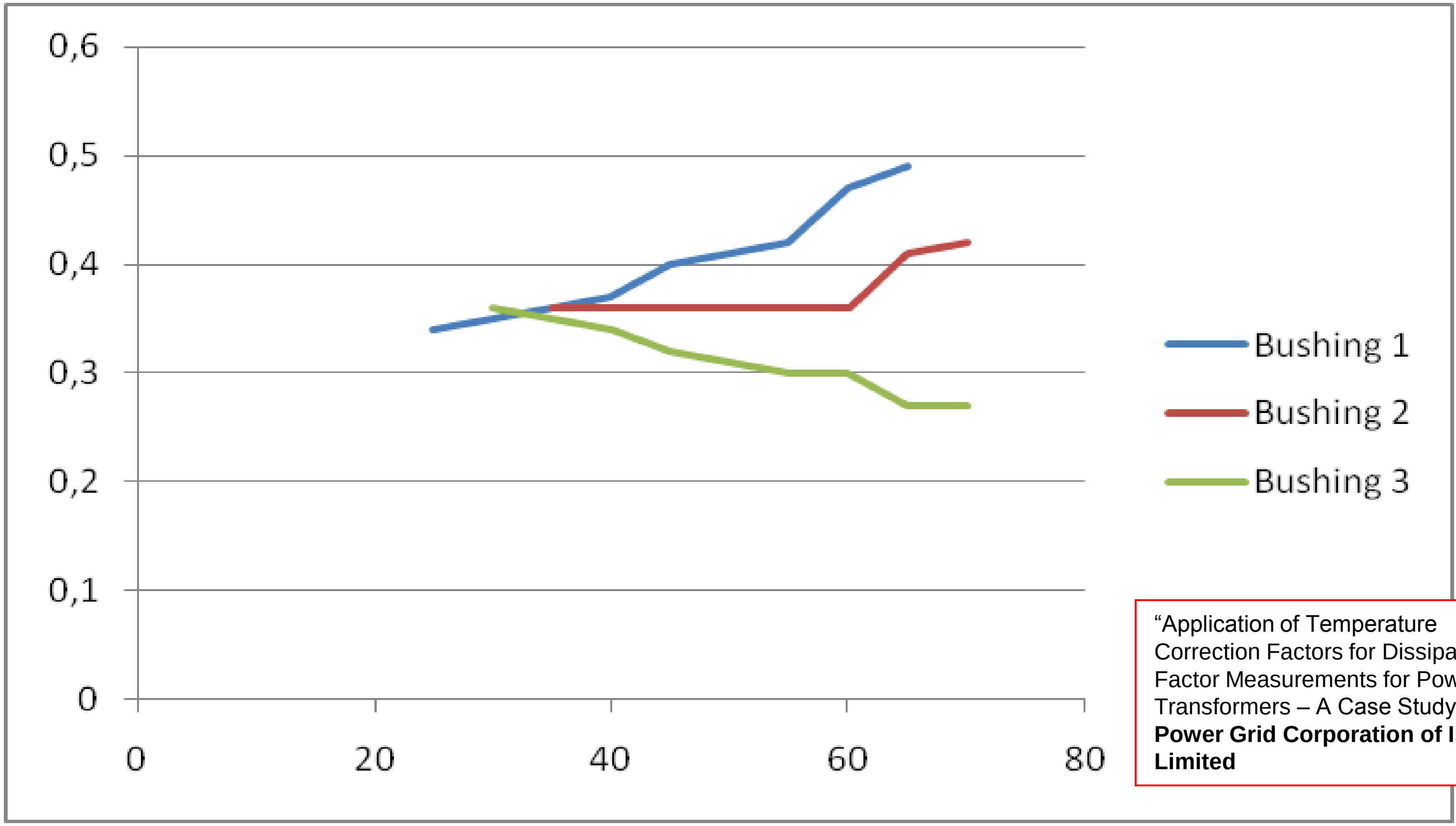
Tan delta (%, 50 Hz) for bushings with different moisture contents



Power factor (%, 60 Hz) for ”good” and ”bad” bushings



Power factor measurements on typical bushings at different temperatures



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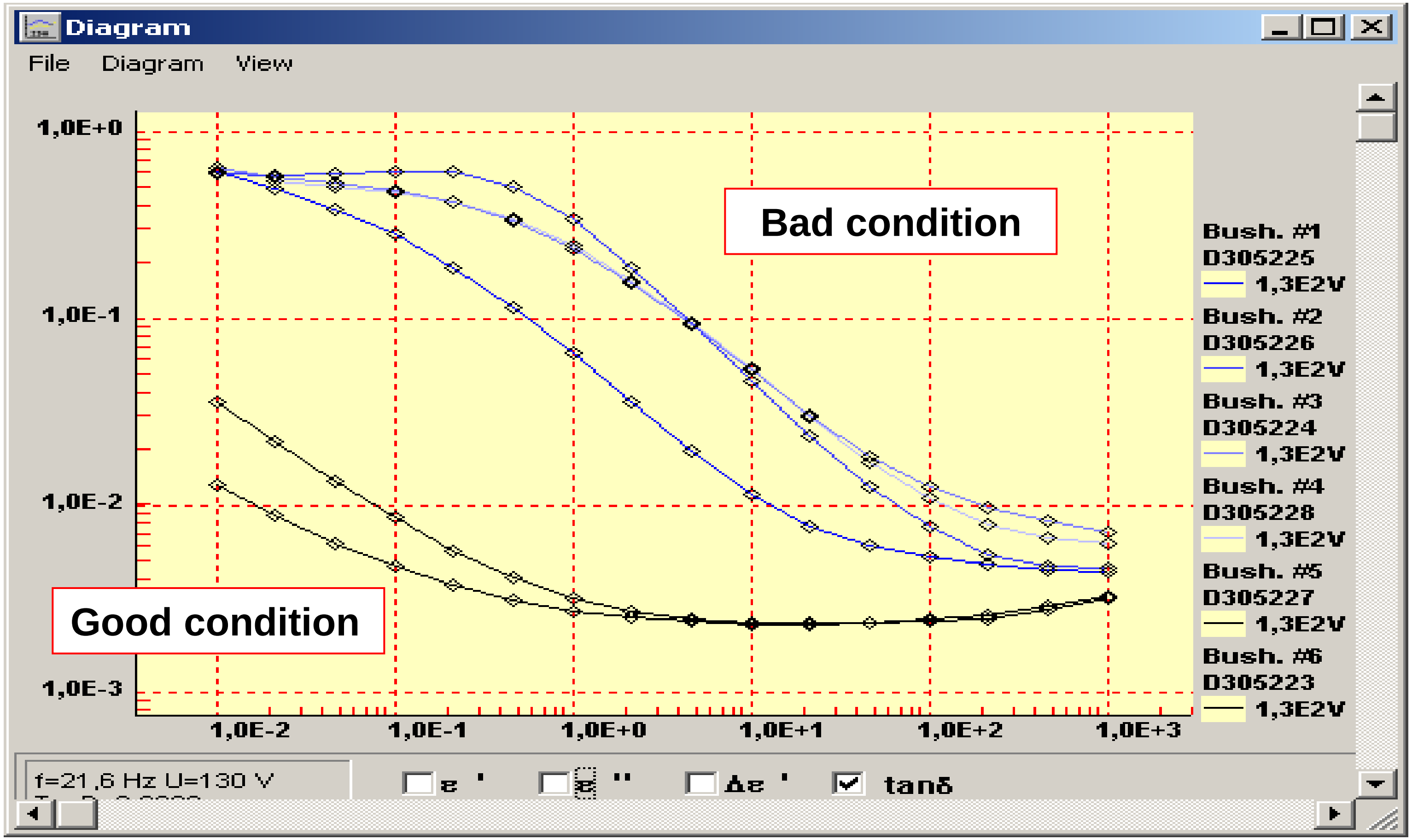
DFR on 115 kV GE Type U bushings in various conditions



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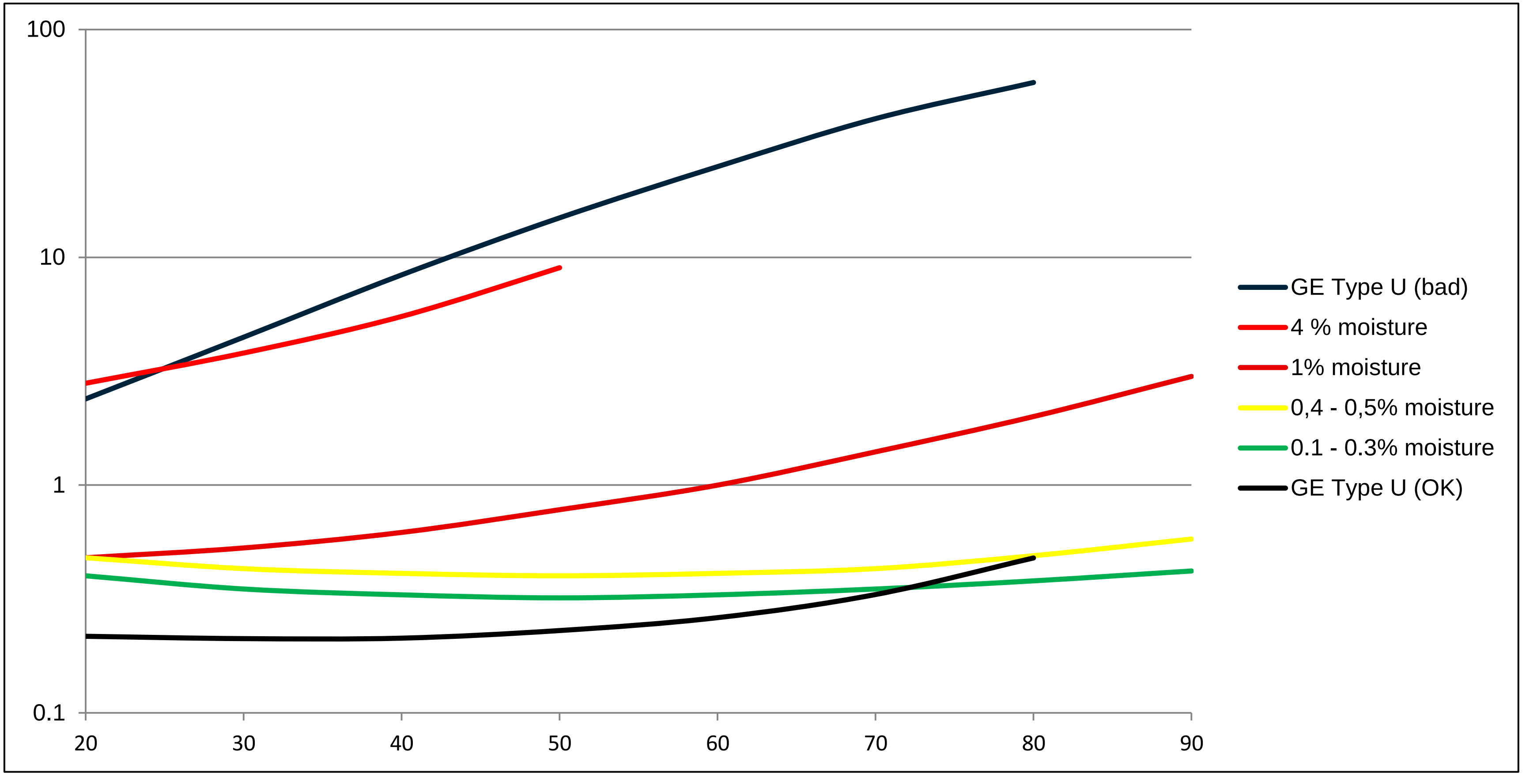
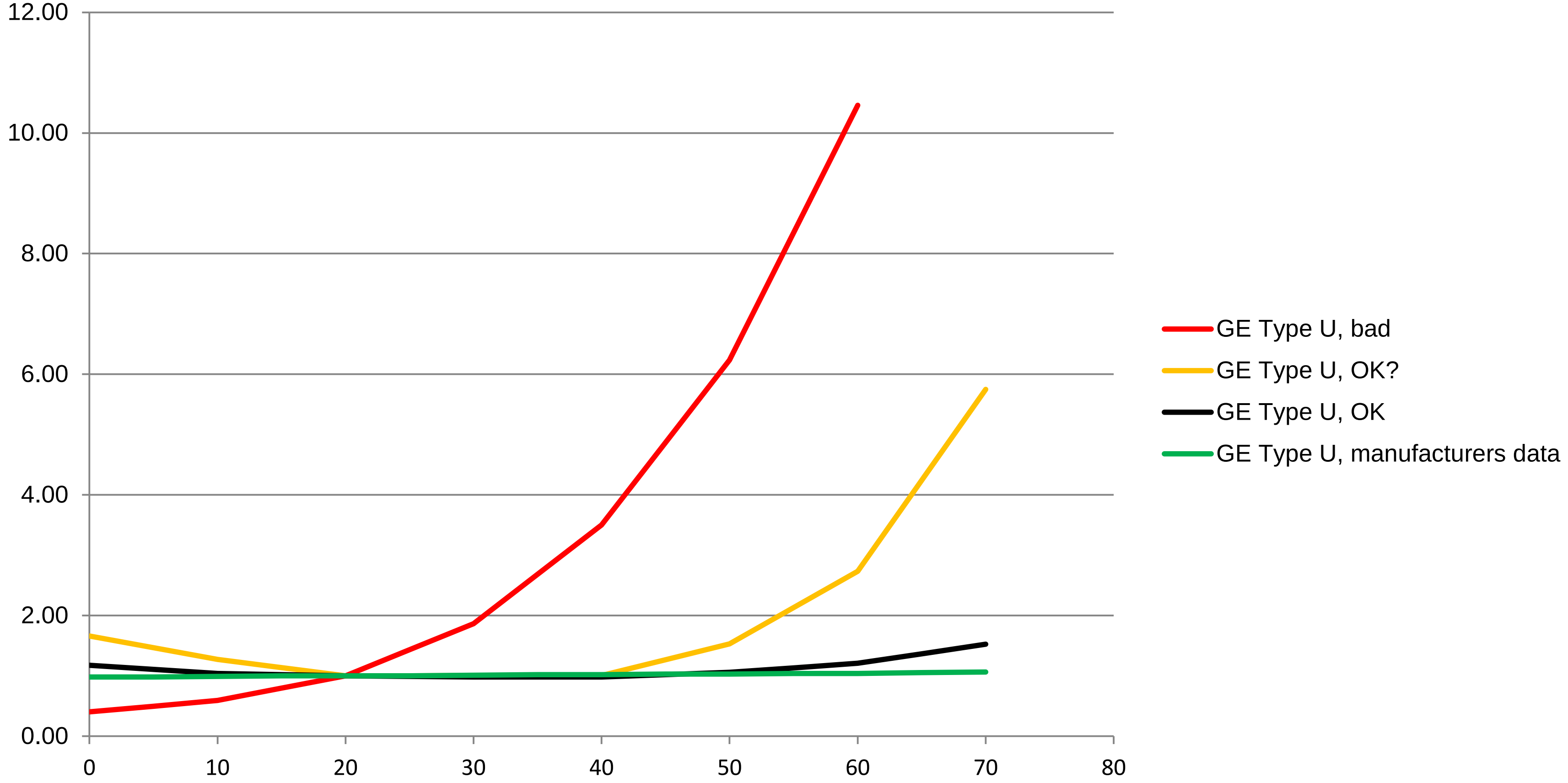
Temperature converted DFR tan delta data for bushings (50 Hz)



Temperature correction of bushings using converted DFR data



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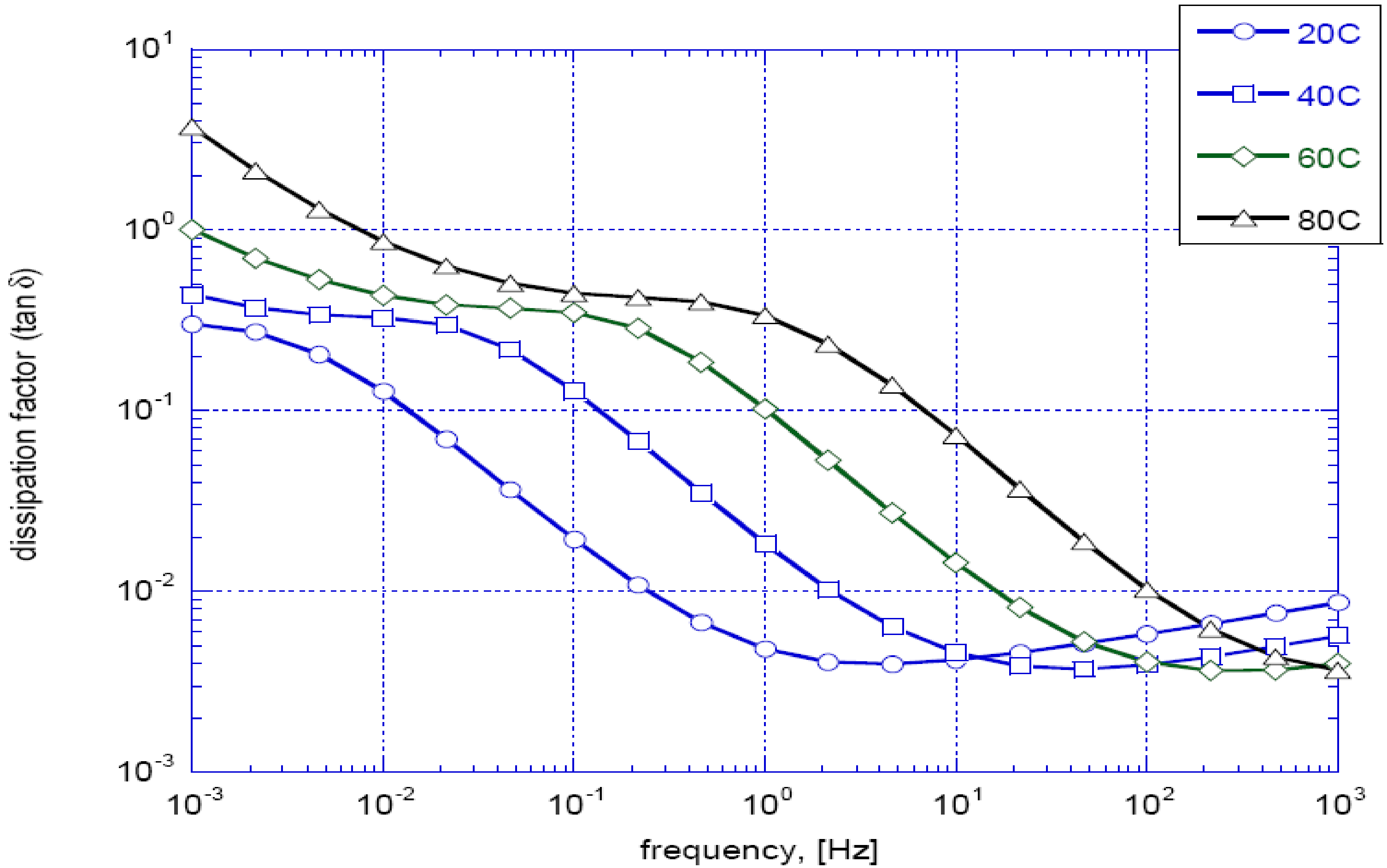
DFR measurements – oil impregnated Kraft paper, moisture content < 0.5%



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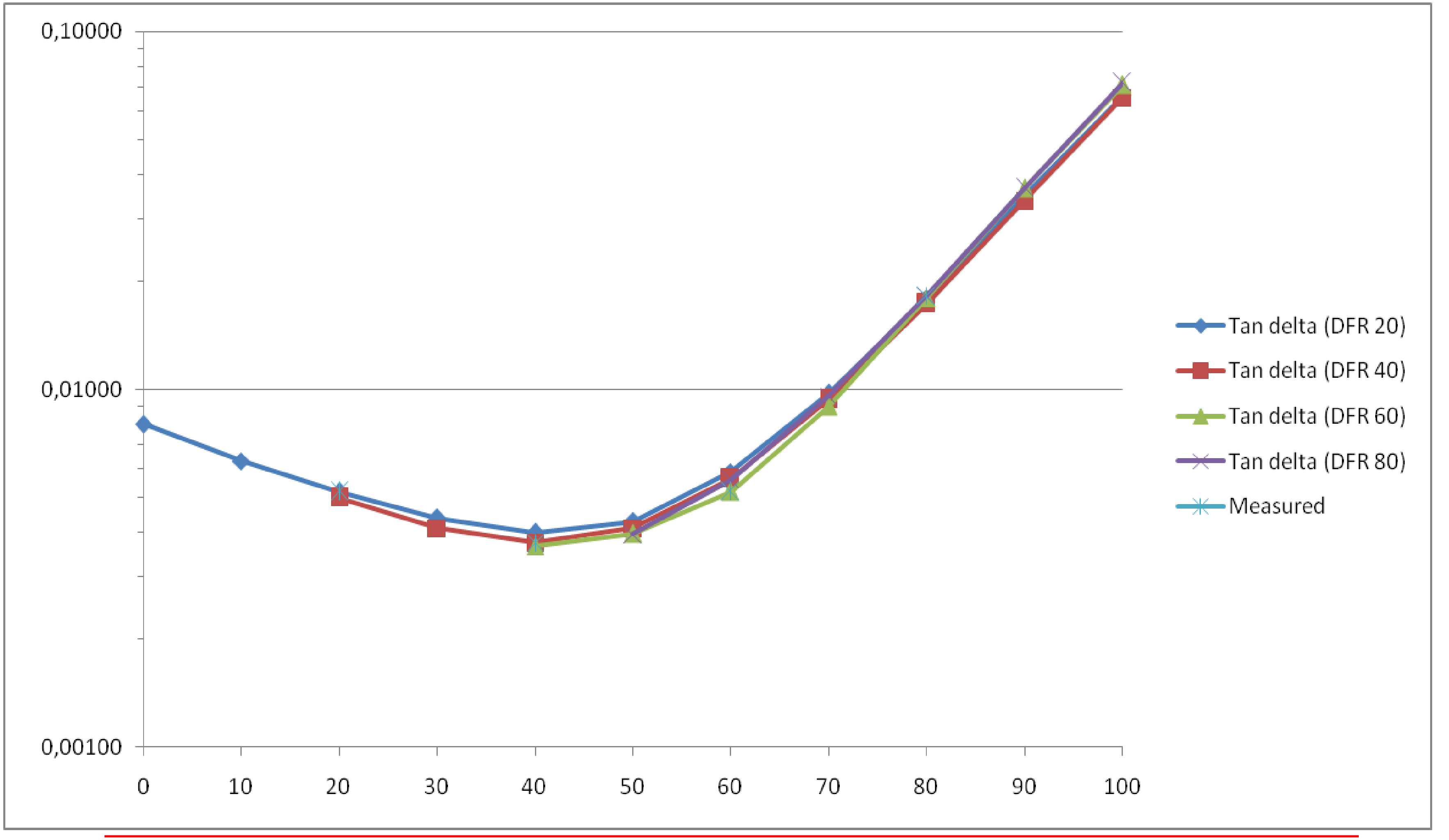
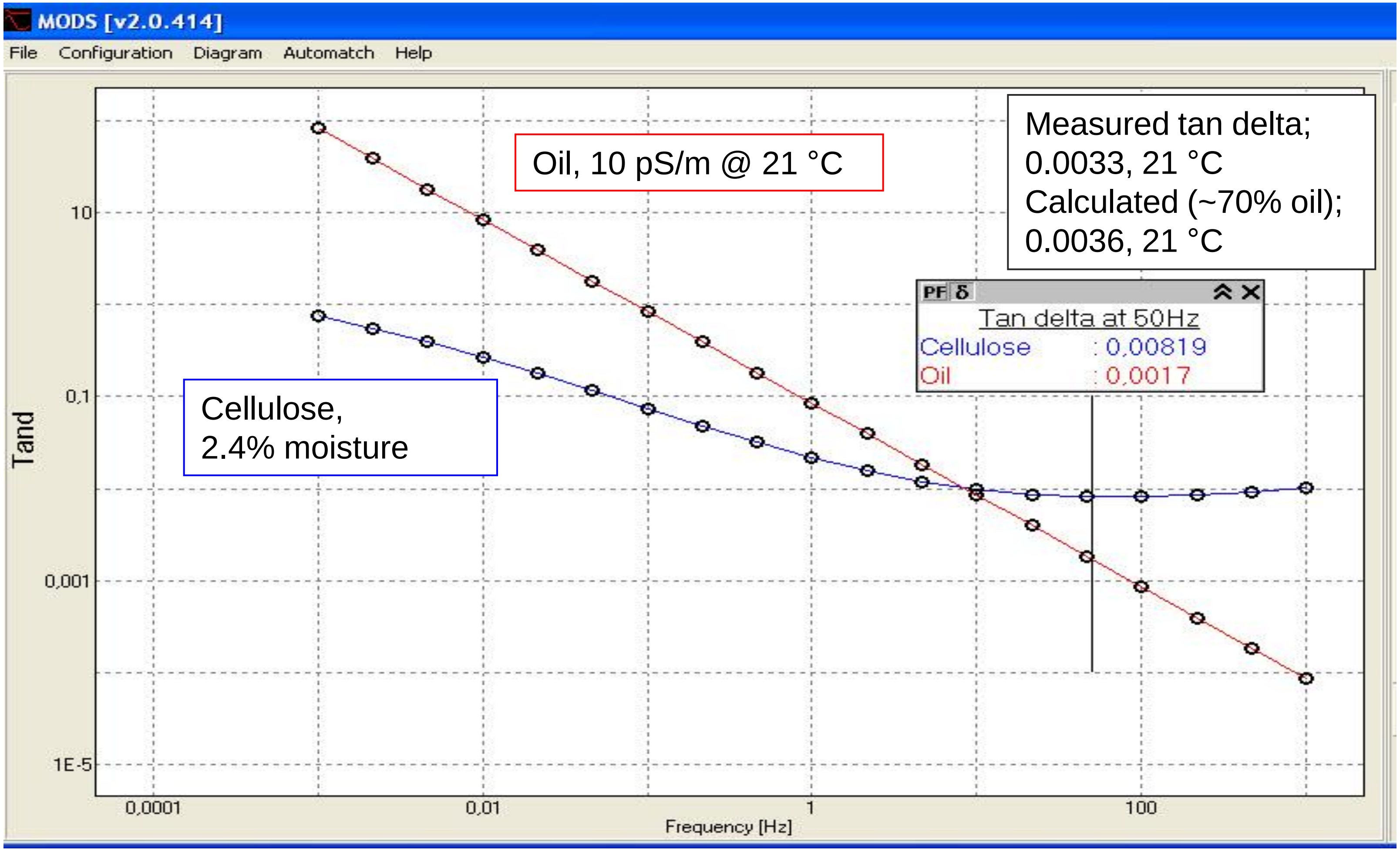
Kraft paper – Tan Delta vs temperature



Temperature dependence in transformers

- Temperature dependence in transformers is more complex compared to “single-material” components e.g. bushings and paper-insulated cables
- Activation energy W_a in Arrhenius’ law, $\kappa = \kappa_0 \cdot \exp(-W_a/kT)$
  - Oil impregnated paper typically 0.9-1 eV
  - Mineral transformer oil typically around 0.4-0.5 eV
- Both materials need to be considered

Modeling oil and solid insulation in a transformer



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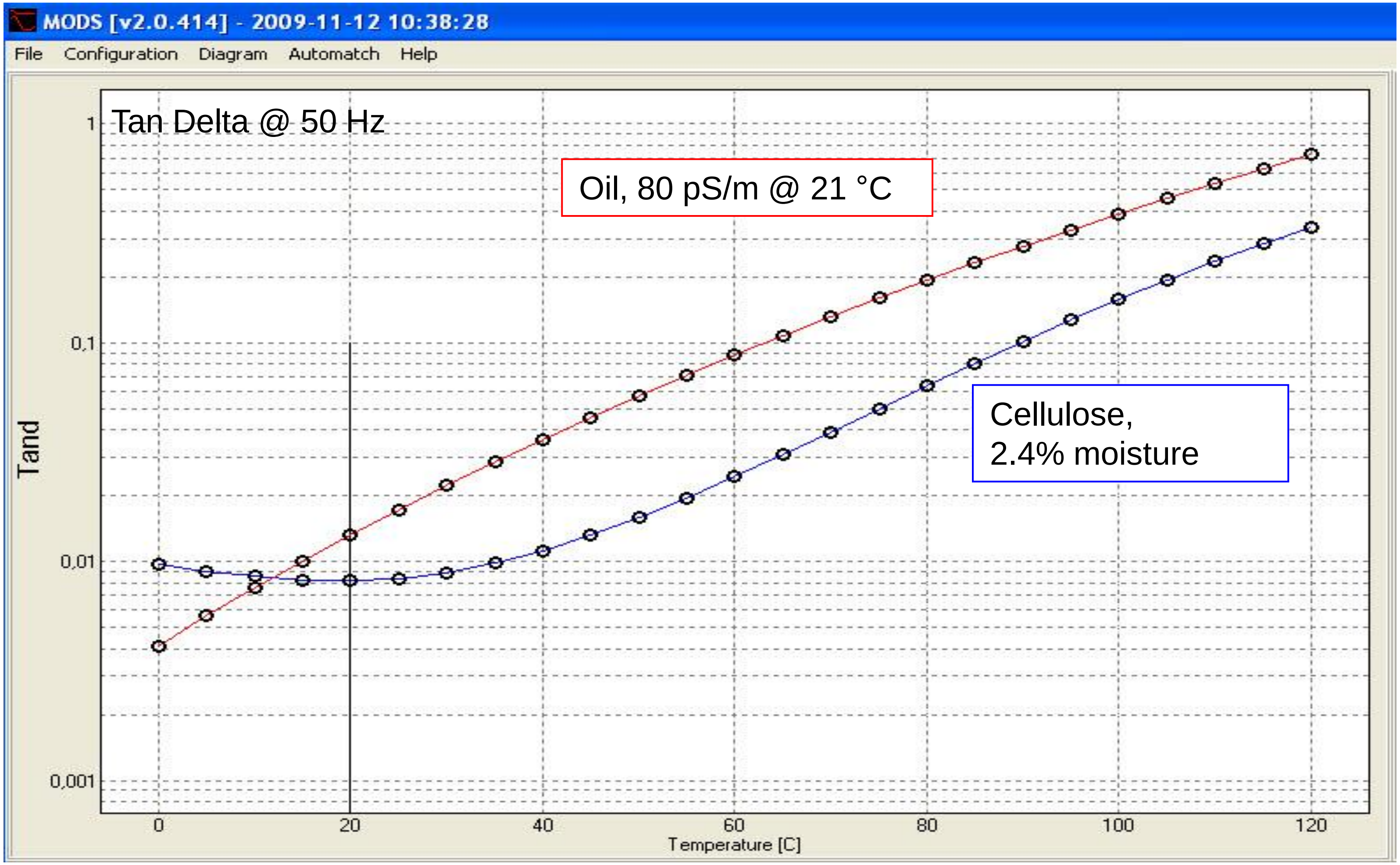
Modeling oil and solid insulation in a transformer

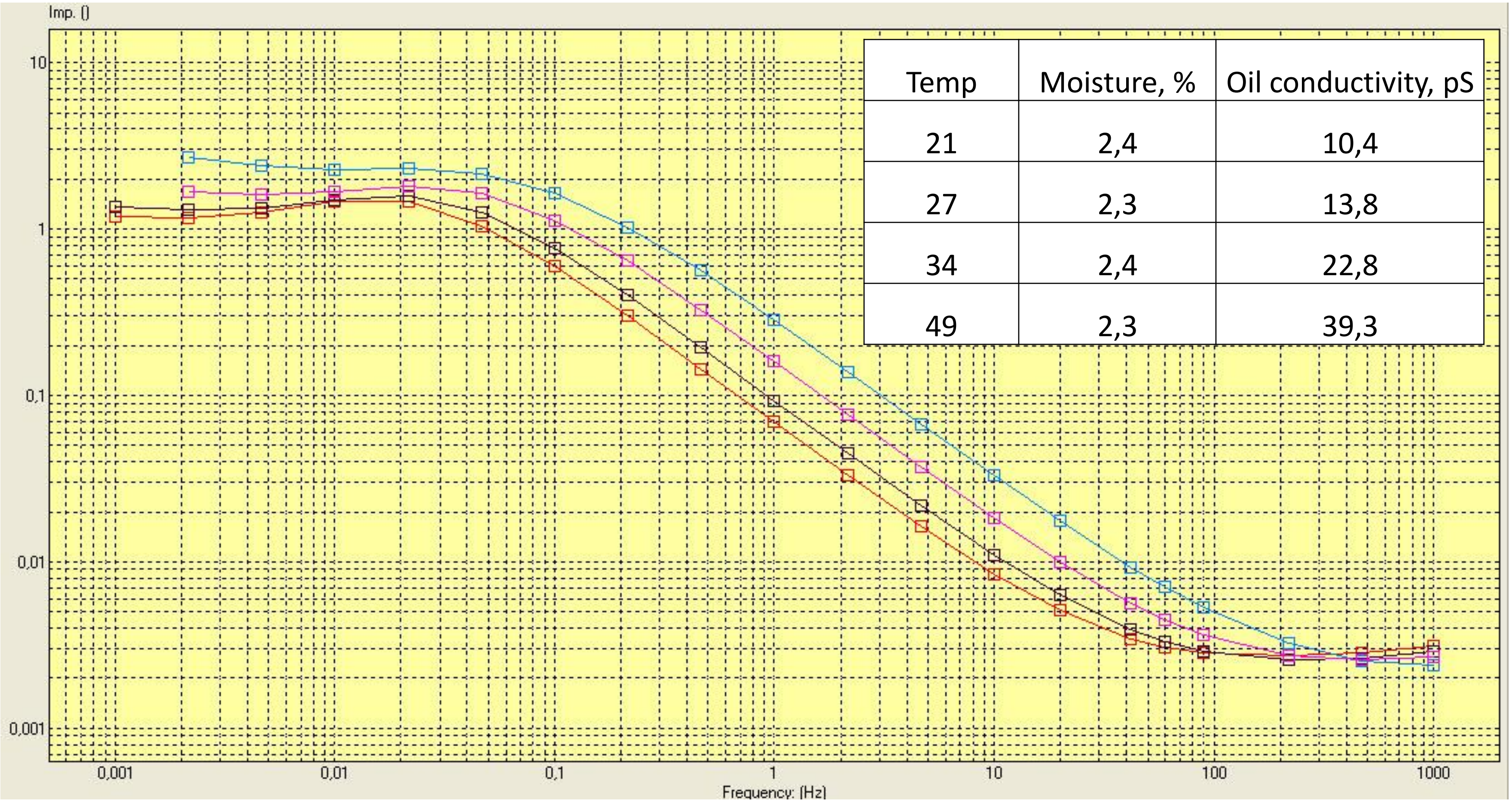


Temperature correction – Transformer

Distribution transformer, 500 kVA, 10.5/0.4 kV

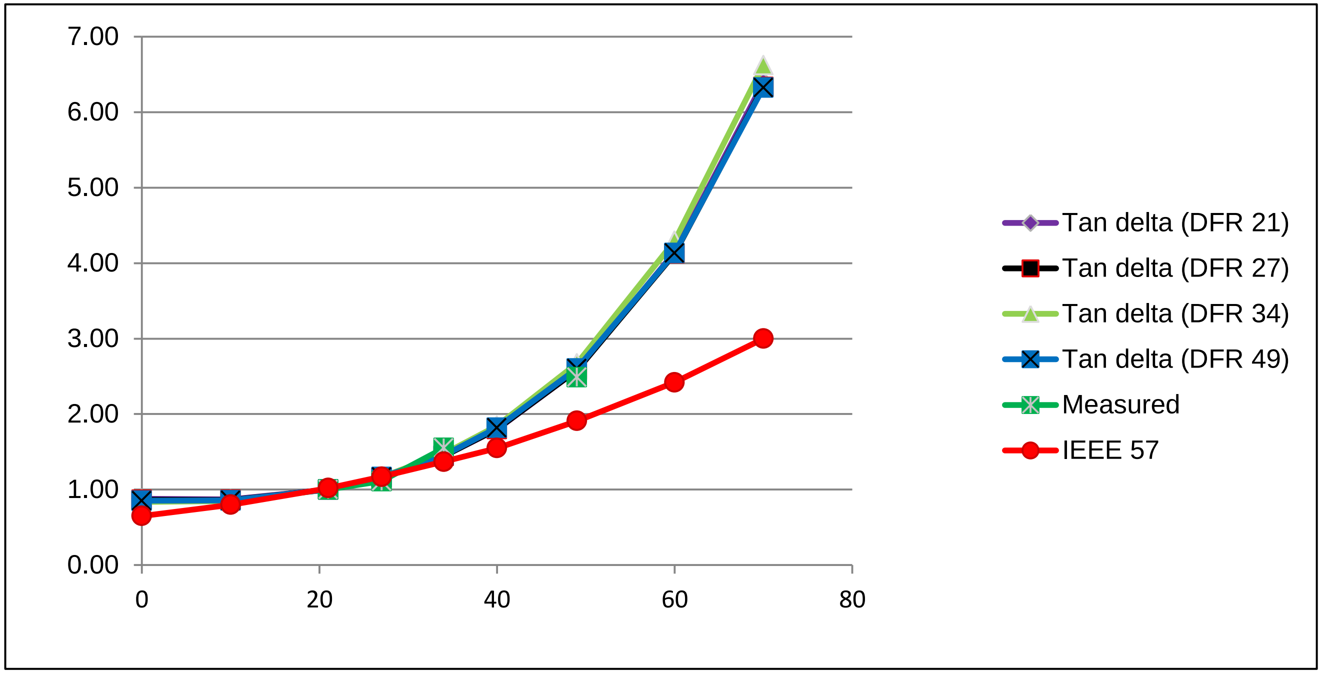
- Heated to different temperatures in the range 20°C-50°C
- Winding temperature measured as winding resistance change
- At each temperature, a DFR measurement was made and;
  - Moisture content of the cellulose insulation was estimated by use of Megger IDAX
  - Temperature correction curve was calculated, also by use of Megger IDAX
  - 50 Hz tan-delta value at 20°C was calculated using the temperature correction curve and compared with table from IEEE C57.12.90-2006.

DFR results for the transfomer at various temperatures



Temp	Moisture, %	Oil conductivity, pS
21	2,4	10,4
27	2,3	13,8
34	2,4	22,8
49	2,3	39,3

Temperature correction



Temp. (°C)	Cap. (pF)	PF (%), measured	Individual Corr. factor	PF (%) @20°C	C57.12.90 Corr. factor	PF (%) @20°C
21	1978	0.329	1.04	0.31	1.02	0.32
26	1976	0.367	1.20	0.31	1.14	0.32
34	1978	0.516	1.53	0.34	1.37	0.38
49	1974	0.832	2.70	0.31	1.91	0.44

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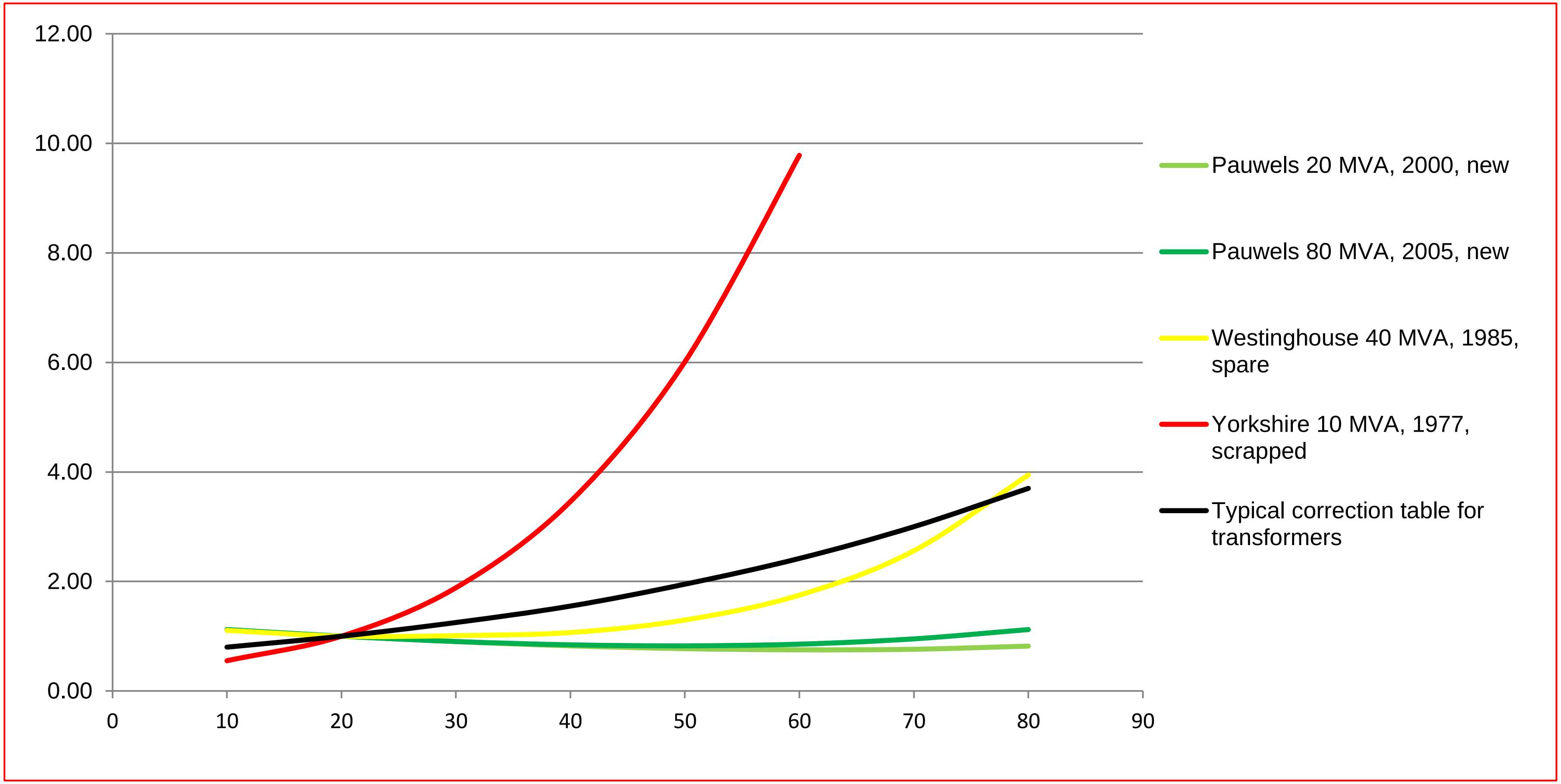
Temperature correction of transformers using converted DFR data



Temperature correction – OIP bushing

ABB GOB OIP bushing

Insulation Temperature, ° C	Measured Power Factor		
	@ 200V	@ 1-10 kV	Comments
-8	0,86	1,04 – 1,14	Voltage dependent at low temperatures
22	0,46	0,46	
42	0,34	0,32	

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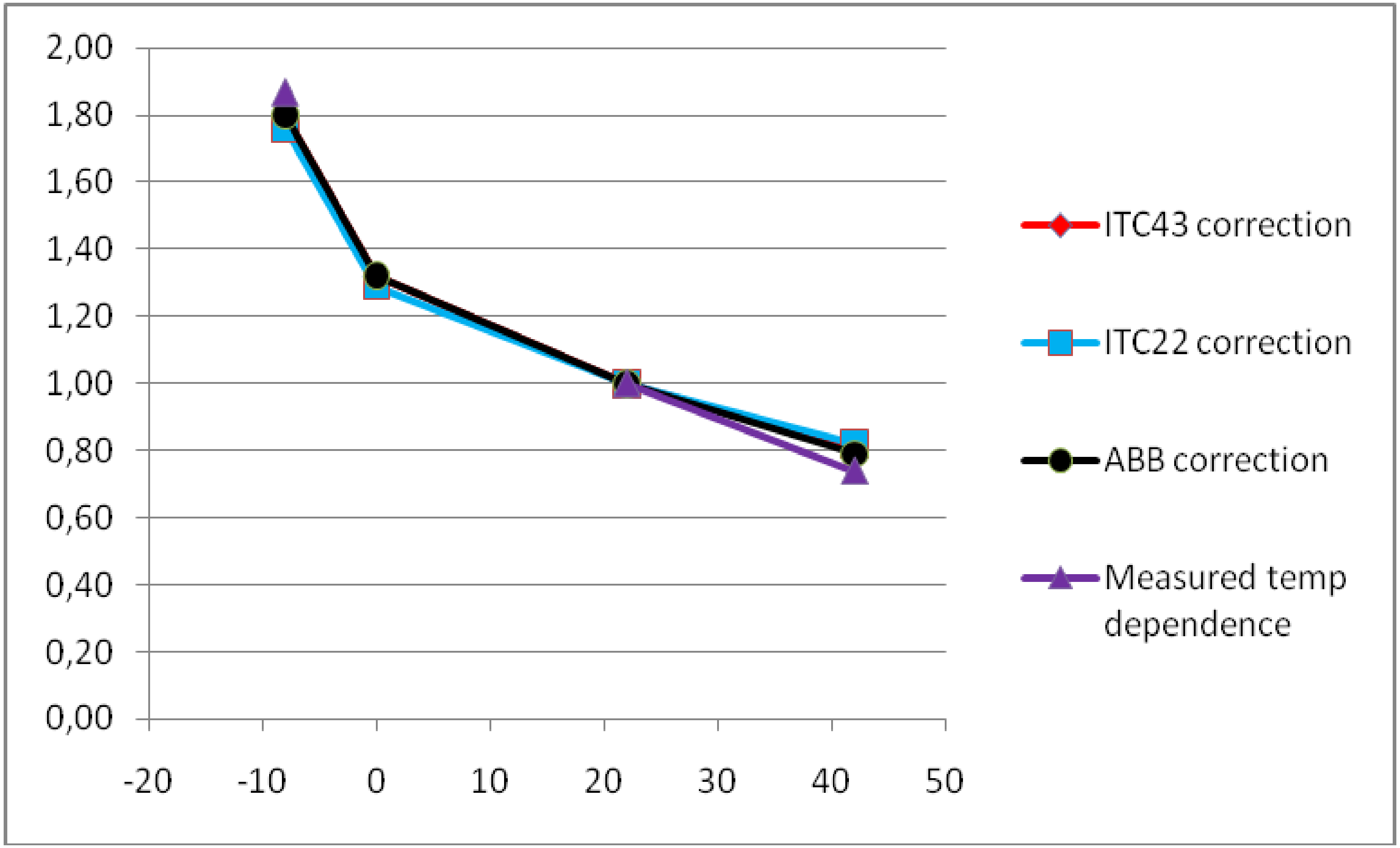
Temperature correction



Summary and conclusions

DFR/FDS measurement/analysis can:

- Investigate increased dissipation factor in power system components
- Estimate the moisture content of oil-immersed cellulose insulation in power transformers, CTs, bushings etc
- Perform individual accurate temperature corrections based on the actual insulation material(-s) and condition (patent pending)

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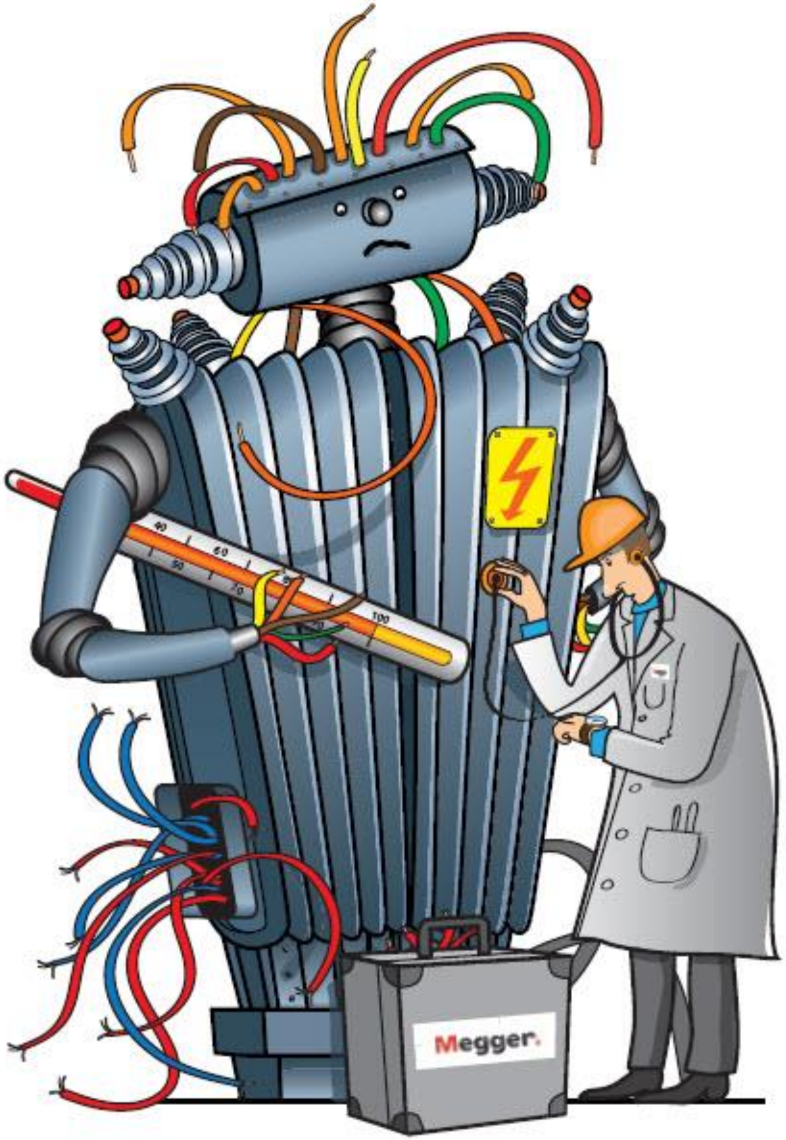

The doctor is in...

Thank you for your attention!